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The AWSUM III_{434} Processor

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A new coherent fluctuation based processor, designed AWSUM III_{434}, is described and results are presented. The processor is a combination of the Wagstaff's Integration Silencing Processor (WISPR) III (WISPR III) and the Advanced WISPR Summation (AWSUM) processor. While WISPR III achieves signal-to-noise ratio (SNR) gains of about 14 dB, AWSUM III_{434} achieves gains of about 24 dB. In addition, the spatial resolution of AWSUM III_{434} is significantly increased and the submerged source identification capability is measurably enhanced, e.g., 10 dB.

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The AWSUM III$_{434}$ Processor

INTRODUCTION

A new coherent fluctuation based processor, designated AWSUM III$_{434}$, is described. The processor is a hybrid of the Wagstaff's Integration Silencing Processor (WISPR) III and the Advanced WISPR Summation (AWSUM) processor[1]. The objective of combining the two fluctuation based processors, one incoherent and the other coherent, was to incorporate some of the positive features of each method into one processor. The equations are given in the next section. That section is followed by a description of the data that were used to test the new processor and finally, results.

GOVERNING EQUATIONS

Consider the complex pressures for a given frequency bin calculated by an FFT from a time series of hydrophone voltages. These complex pressures, which also form a time series, may be either the output from a single hydrophone, or the beamformed output from an array of hydrophones. Let the set $\{z_n\}$ (n = 1, 2, ...,N) denote the complex pressures from a single hydrophone or from a single beam. The nth complex pressure is of the form

$$z_n = r_n u_n \qquad (1)$$

where r_n is the magnitude, and u_n is the complex phase factor. This phase factor is of the form

$$u_n = \exp\{i[\theta_n + 2\pi f n \Delta t]\} \qquad (2)$$

where f is the frequency, and Δt is the time delay between the successive FFTs. The phase factors corresponding to the time delay Δt can be removed from the set $\{u_n\}$, yielding a new set $\{v_n\}$ as

$$v_n = u_n \exp(-i2\pi f n \Delta t) = \exp[i\theta_n]. \qquad (3)$$

The average of the set $\{v_n\}$ is given by

$$\bar{s} = \frac{1}{N} \sum_{n=1}^{N} v_n \,. \tag{4}$$

Now defining an AWSUM value A_m as

$$A_m = \left[\frac{1}{N} \sum_{n=1}^{N} r_n^{\,-m} \right]^{-1/m} , \tag{5}$$

the AWSUM III_{434} value is taken to be

$$AIII_{434} = \{[A_4 - (A_3 - A_4)]\,|\bar{s}|\}^2 . \tag{6}$$

The corresponding average AWSUM III_{434} level in decibels is

$$AIII_{434dB} = 10 \log AIII_{434} \,. \tag{7}$$

The conventional definition of the average power for the set $\{z_n\}$ is

$$P = \frac{1}{N} \sum_{n=1}^{N} |z_n|^2 , \tag{8}$$

and the corresponding average power level in decibels is

$$P_{dB} = 10 \log P. \tag{9}$$

The WISPR III value can be expressed using the definition of Eq. (5) above as

$$WIII = \{A_1 |\bar{s}|\}^2 , \tag{10}$$

and the WISPR III level can be written as

$$WIII_{dB} = 10 \log WIII. \tag{11}$$

For a beam containing a steady tonal such as that from a submerged source, the level $AIII_{434dB}$ would be nearly equal to the power level P_{dB}, and therefore the quantity (P_{dB} - $AIII_{434dB}$) would be nearly zero. In contrast, the quantity (P_{dB} - $AIII_{434dB}$) would have a relatively large positive value for a noise beam. Thus steady tonals would stand out as peaks in a plot of the quantity (P_{dB} - $AIII_{434dB}$), where increasing values are represented along a coordinate pointing vertically downward.

EXPERIMENTAL DATA

The data used below in the evaluation of the AWSUM III_{434} processor was taken from a SURTASS measurement exercise conducted approximately 50-100 miles south of Oahu, HI, starting Dec. 11, 1993. A surface ship towed a line array of 144 hydrophone receivers, uniformly spaced at approximately 12.65 m. Two submarines were present in the region; one stable tonal was detected from each. The objective of the following analysis was to detect those tonals with the AWSUM III processor described above. The bottom depth of the oceanic region was between 3000 and 6000 m.

The data of hydrophone output voltages were digitized at a sampling rate of 200 Hz. In the analysis, 2048 point FFTs (with Hann weights) were performed, with 75% overlap of the voltage time series between successive FFTs. To facilitate the description of the technique, the complex pressures of a given frequency bin from the successive FFTs for each of the 144 hydrophones were labeled as sample #1, #2, etc. for that hydrophone. A total of 47 such samples for each hydrophone were included in the analysis. For the n^{th} such sample (n = 1, 2,...,47), beamforming was performed in hydrophone space using a 256 point FFT (with Hann weights for the 144 hydrophones, and zero padding for bins 145 through 256), generating 256 beams. The successive values of each beam were then relabled as sample #1, #2, etc. This resulted in 256 beams, with 47 complex valued samples for each beam. This is the data set used in the analysis below. For each of the frequency bins of interest, there is one such data set.

RESULTS

The AWSUM III_{434} processor is compared with the WISPR III processor, as a standard, in four figures. The first two figures present beam number-frequency surfaces of all the data. The remaining two figures present slices across beam number at two frequency bins containing a signal from a submerged source. The AWSUM III_{434} results are in the top plots and the corresponding WISPR III results are in the bottom plots.

The AWSUM III_{434} levels are plotted in Fig. 1(a) as a function of beam number and frequency bin number (1 frequency bin = 0.09765 Hz). There is less clutter in this plot than in the corresponding plot of the WISPR III level in Fig. 1(b). The broad peak in the vicinity of frequency bin #154, beam #137 has a narrow sub-peak just at the right location of the stable tonal. This sub-peak is absent in the plot of the WISPR III level.

The quantity (P_{dB} - $AIII_{434dB}$) is plotted in Fig. 2(a) as a function of beam number and frequency bin number. The two known tonals from submerged sources stand out as peaks at frequency bin #54, beam #118 and at frequency bin #154, beam #137. The peaks are approximately 1 dB taller above the noise background, compared to the corresponding peaks for WISPR III in Fig. 2(b).

Slices at frequency bin #54 plotted as functions of beam number are included in Fig. 3. The top curves give the average power level P_{dB}.The location of the signal from the submerged source is indicated by the vertical arrows. The middle curves give the a) AWSUM III levels $AIII_{434dB}$ and b) the WISPR III levels, $WIII_{dB}$, and the bottom curves give the quantity (P_{dB} - $AIII_{434dB}$). The horizontal arrows show the bottom curve approaching the 0 dB line at the location of the submerged source signal. It is this feature of the AWSUM III_{434} processor that gives it an unalerted auto-detection capability. The average noise background in the bottom curve of Fig. 3 (a) is approximately 10 dB higher (more suppressed from the submerged source signal response) than the corresponding background for WISPR III in Fig. 3(b). This enhancement due to the AWSUM III_{434} processor improves the detection of the submerged source tonal, represented by the dip in the bottom curve at beam #118, by about 10 dB, approximately 24 dB better than the average power processor, P.

Comparison of the middle curves for $AIII_{434dB}$ in Fig. 3(a) and $WIII_{dB}$ in Fig. 3(b) shows the higher resolving power of the AWSUM III_{434} processor. For example, the small peak to the right and about 15 dB below the submerged source signal response of $WIII_{dB}$ in Fig. 3(b) is separated from the main response by a null of about 4 dB. The corresponding null in the $AIII_{434dB}$ curve in Fig. 3(a) is about 15 dB. In addition, the single peak in the $WIII_{dB}$ results near beam number 130 is divided into two peaks in the $AIII_{434dB}$ results. In general, the responses in the $AIII_{434dB}$ results clearly show the effects of substantially enhanced resolution compared to the corresponding $WIII_{dB}$ results.

Figure 4 presents results similar to Fig. 3(a) for frequency bin #154. In like manner, the arrows give the location of the signal from the submerged source, demonstrate the unalerted auto-detection

capability, and show improvement of the AWSUM III_{434} processor over the WISPR III processor. The average noise background in the bottom curve of Fig. 4 (a) is approximately 10 dB higher than the corresponding background for WISPR III in Fig. 4(b). This substantially improves the detection of the submerged source tonal represented by the dip in the bottom curve at beam #137.

The enhanced resolution of the AWSUM III_{434} processor is clearly evident in the results of Fig. 4. The response of the WISPR III processor near the signal from the submerged source shows only a single broad peak. However, the corresponding response of the AWSUM III_{434} processor shows two peaks, a narrow one at the source location and a broader one adjacent to it.

CONCLUSIONS

The AWSUM III_{434} processor out-performed the WISPR III processor in both SNR gain and spatial resolution. While the WISPR III processor achieved about 14 dB gain improvement over the average power processor, the AWSUM III_{434} processor achieved about 24 dB gain improvement. Furthermore, although the spatial resolution was not quantified for any of the processors, a cursory visual comparison indicated that the spatial resolution of the AWSUM III_{434} processor was much greater than that of the WISPR III processor.

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1. R. A. Wagstaff, and J. George, "Phase Variations in Fluctuation-Based Processor," proceedings of the SPIE Aerospace / Defense Sensing and Controls '96 Symposium, Targets and Background: Characterizations and Representation II Conference, Vol.. 2751, pp. 132-141, Apr. 1996.

Figure 1(a)

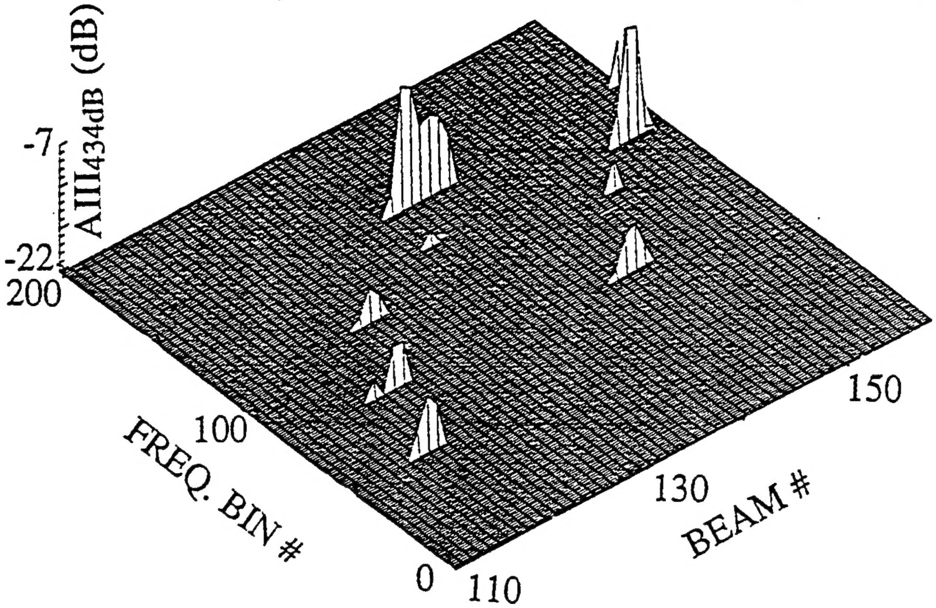


Figure 1(b)

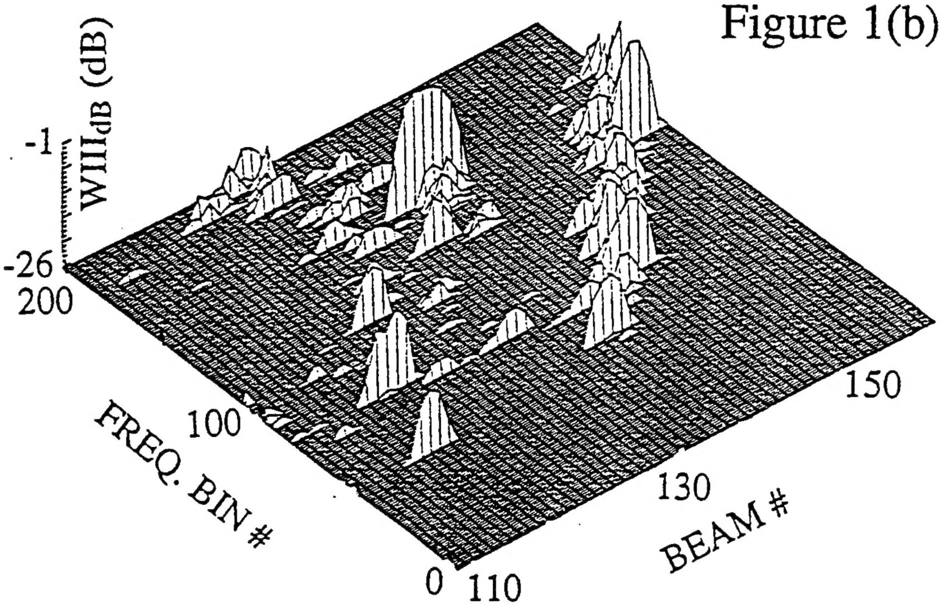
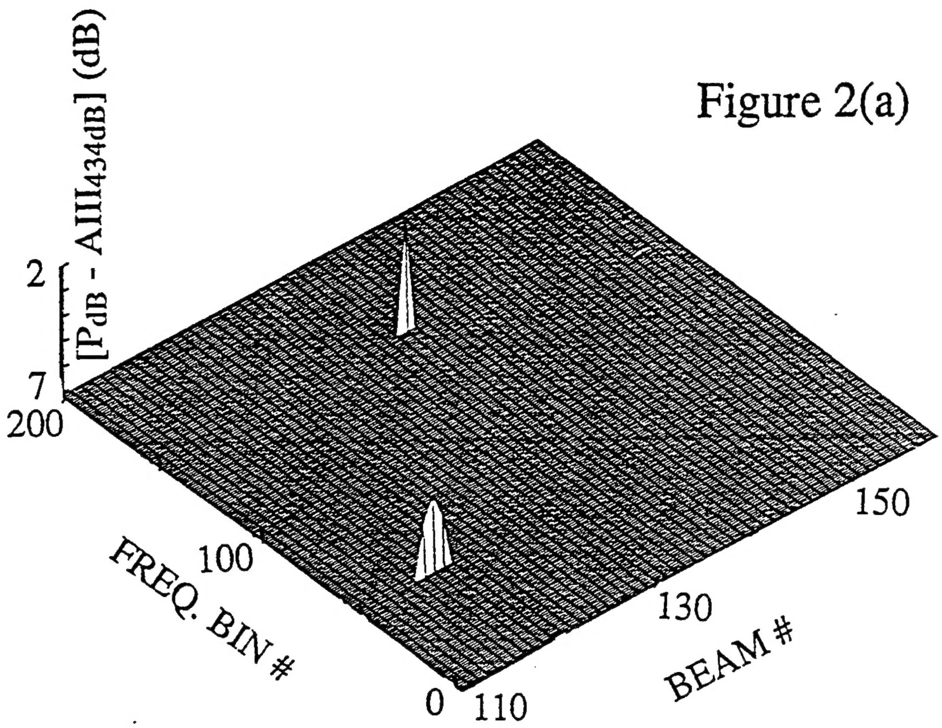


Figure 1. Surface plot of frequency bin versus beam number for a) $AIII_{434dB}$ and b) $WIII_{dB}$.



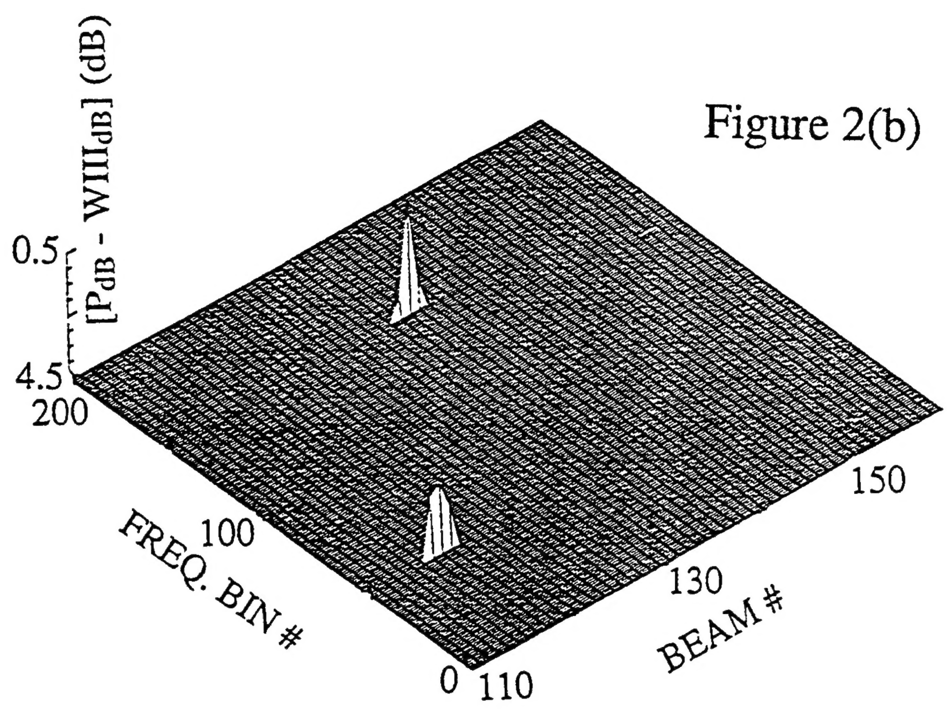


Figure 2. Surface plot of frequency bin versus beam number for a) (P_{dB} - $AIII_{434dB}$) and b) (P_{dB}- $WIII_{dB}$).

Figure 3(a)

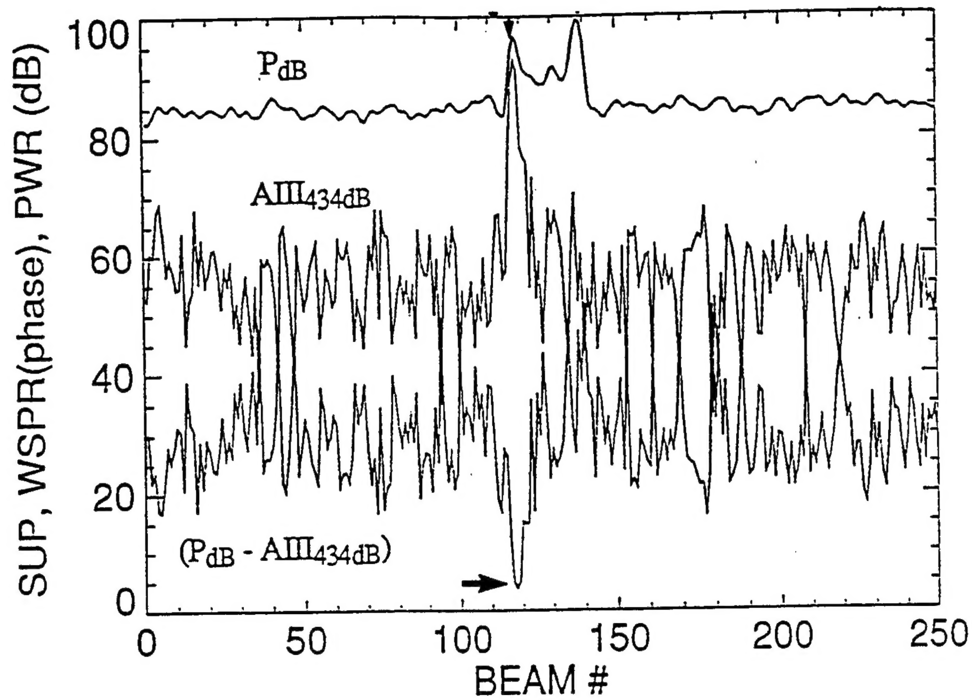


Figure 3(b)

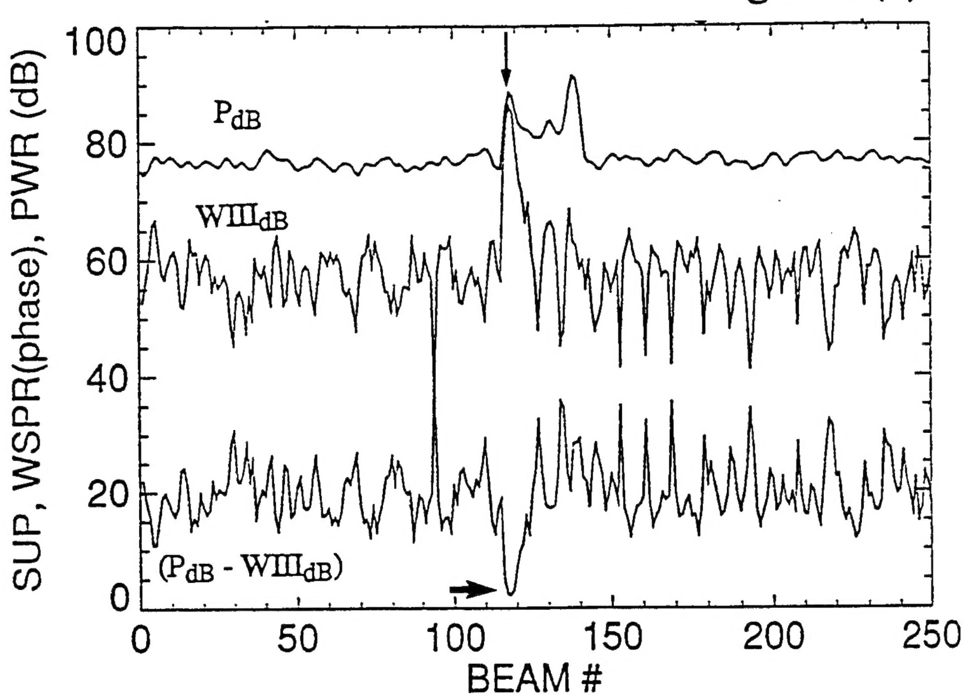


Figure 3. Slices at frequency bin #54 plotted as functions of beam number. The top curves give the average power levels P_{dB}. The location of the signal from the submerged source is indicated by the vertical arrows. The middle curves give the a) AWSUM III level, $AIII_{434dB}$, and the b) WISPR III levels, $WIII_{dB}$. The bottom curves are the differences between the other two curves. The horizontal arrows show the locations of the signal from the submerged source.

Figure 4(a)

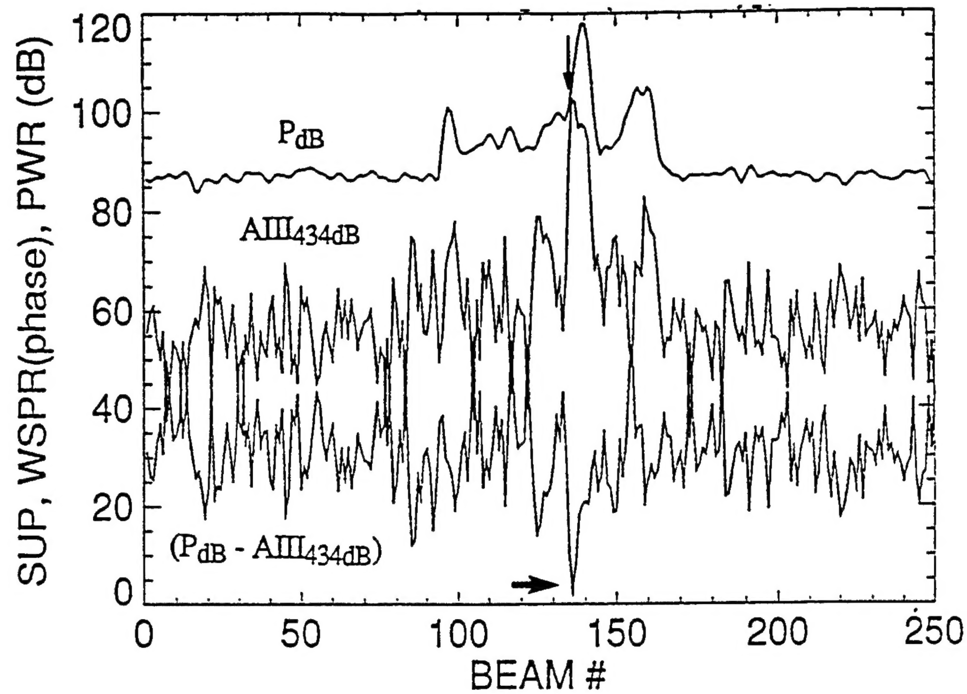


Figure 4(b)

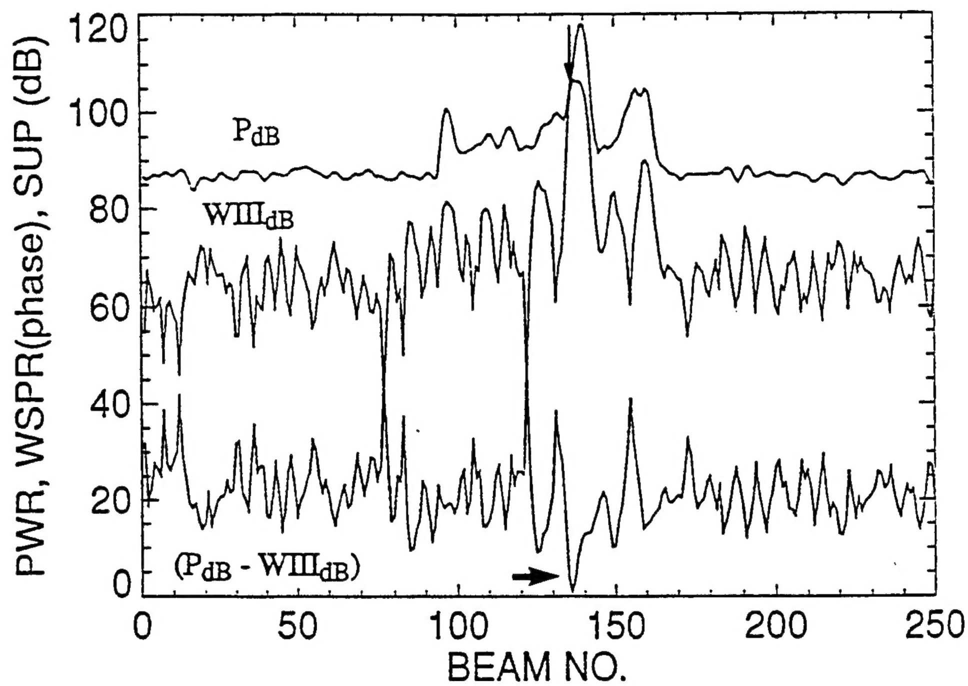


Figure 4. Slices at frequency bin #154 plotted as functions of beam number. The top curves give the average power levels P_{dB}. The location of the signal from the submerged source is indicated by the vertical arrows. The middle curves give the a) AWSUM III level, $AIII_{434dB}$, and the b) WISPR III levels, $WIII_{dB}$. The bottom curves are the differences between the other two curves. The horizontal arrows show the locations of the signal from the submerged source.